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AUTHOR Osborne, Roger; Schollum, Brendan
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ABSTRACT

In the action-research phase of the Learning in Science Project, four groups of people worked on problems identified in the project's second (in-depth) phase. The Physics action-research group considered problems related to the teaching and learning of ideas associated with force and motion, suggesting that children's ideas of these concepts might be modified by a "force through momentum" approach. The approach builds on children's intuitive ideas of the physicists' momentum concept, introduces the label "momentum" for that concept, and separates out for children the distinct difference between momentum and force. Three types of materials were developed to implement the approach: (1) a booklet containing background information on typical children's/scientists' views on force, friction, and gravity; (2) a booklet providing specific teaching activities directly useable in classrooms; and (3) inservice course material. Classes were surveyed prior to and after the teaching sequence using survey A and survey B (the latter included in an appendix). Although some children had modified their views, there was increase (after instruction) in the number of students who considered momentum to be a force. (Typical survey results and a partial interview transcript of the student who changed his views during one of the trials are included in appendices.) (JN)

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LEARNING IN SCIENCE PROJECT

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TOWARD SOLUTIONS:

The work of the

Physics Action–Research Group

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WORKING PAPER No. 32

PHYSICS ACTION-RESEARCH GROUP

Roger Osborne (Co-ordinator)

Bronwen Cowie

Graham Hill

Bill Neate

Nigel Pettigrew

Alister Riddel

Brendan Schollum

Jill Skinner

Len Smith

Ross Tasker

Our thanks to many others who helped with aspects of the action-research including in particular, Peter Freyberg, David Hood, Gillian Tasker and Colin Telford.

THE WORK OF THE PHYSICS ACTION-RESEARCH GROUP

Roger Osborne and Brendan Schollum

November 1981

INTRODUCTION:

In the action-research phase of the Learning in Science Project four groups of people worked on problems identified in the in-depth phase of the Project. The Physics action-research group considered problems related to the teaching and learning of ideas associated with force and motion; problems which had earlier been identified in three working papers, Force (No. 16), friction (No. 19) and Gravity (No. 20).

The group was chosen to provide a variety of experiences in teaching and a range of academic backgrounds in physics. It consisted of practising classroom teachers and Learning in Science Project team members. Prior to the first meeting of the group in February 1981 individuals were sent the three working papers of the in-depth phase - Force, Friction and Gravity, and asked to consider whether the problem and difficulties described in these papers related to real, important and possibly solvable issues.

THE FIRST MEETING

The initial meeting of the group was held early in the year. The group collectively agreed that the problems identified by the papers appeared real and important issues which have not been confronted by existing curriculum materials. The group, however, could not agree so readily on the age level at which efforts to solve some of the problems should be made. However it was generally accepted that the scientific view of force is basically a simple idea and one that is needed to be held by at least one group of children - our future scientists and technologists. It was also agreed that the scientists' concept of force is a central and basic topic in the understanding of science and the topic is certainly along the path children need to tread if they are to find out about the scientists' view of the world.

With respect to what might be done to resolve some of the problems identified in the force, friction and gravity papers a number of points were agreed to;

i) frictional forces, reaction forces and momentum are concepts that have been played down by teachers but they are fundamental ideas,

ii) a major priority must be to improve the teachers' understanding of both scientists' views on the one hand and children's views on the other,

iii) the opportunity must be provided for children to clarify their own views and for these views to be valued,

iv) scientific ideas about force, friction and gravity must be linked to the everyday experiences of pupils and, in teaching, there is a need to provide many examples and non-examples of any one concept.

THE SECOND MEETING

At the end of the first term the group met again. During the first term many members of the group had checked out whether or not the problems identified in the working papers were, in fact, problems in their own schools. The general consensus was that indeed they were - survey results they obtained with pupils in their schools were similar to the results reported in the working papers.

It would be fair to say that members of the group found some difficulty in suggesting innovative teaching strategies which might help to overcome the problems identified in the working papers. One suggestion put up by the LISP team however did appear to be worthy of investigation. The proposed teaching strategy, which will be explained more fully in the next section, was somewhat unorthodox. However it did appear to be centrally concerned with attempting to modify, rather than ignore, children's intuitive ideas. An outline of possible teaching activities based on the proposed strategy, which we will call the "force through momentum" approach, was developed and a number of members of the group and others agreed to trial the approach in their own classrooms.

About this time the type of material that might be produced for teachers, and others, by the action-research group was becoming clear. It was proposed that:

i) A booklet should be produced (Working Paper No. 33) which provided teachers with background information on typical children's views, and scientists' views, with regard to force, friction and gravity. The booklet should also provide teachers with the opportunity to clarify their own views with regard to these topics.

ii) A booklet should be produced (Working Paper No. 34) which would provide teachers with specific teaching activities directly useable in classrooms. These teaching materials should provide surveys to check on children's ideas both prior to, and after, teaching; material which would enable children to have classroom discussion about their ideas; and also worksheets and activities to enable pupils to have key experiences. Consideration should also be given to worksheets and explanations directly usable by pupils.

iii) In-service course material should be produced (Workshop Package - Force) consisting of video tape, OHP materials, discussion documents, as well as the booklets described under i) and ii) above.

THE TEACHING 'FORCE THROUGH MOMENTUM' IDEA

One of the major philosophical viewpoints arising from the work of the in-depth phase of the LISP work (see Working Paper No. 28) was that with respect to a number of topics in science, learning might well be more appropriately viewed as a modification of children's early intuitive ideas toward the scientists' viewpoint. rather than the absorption of scientific ideas by blank minds (see Gilbert, Osborne & Fensham, 1982). Many children's ideas about force, friction and gravity (see Working Paper No. 33) need modification if they are to more closely relate to the scientific viewpoint. However in our view one of the most central and important ideas that needs to be modified is the fact that the physicists' concept of momentum is intuitively appreciated by many children but it is labelled by children as a force.

Forces to physicists are basically pushes and pulls which act on an object, whereas to many children they are also quantities which are in moving objects by virtue of their motion and which cause the object to move forward (again see Working Paper No. 33). This suggested to us that children's ideas might well be most successfully modified if we,

i) build on children's intuitive idea of the physicists' momentum concept,

ii) introduce the label momentum for that concept, and

iii) separate out for children the distinct difference between momentum and force.

This is the basis of the force through momentum approach.

From a theoretical perspective there were two additional reasons why the momentum approach seemed worth trying. Firstly Raven (1967-8) showed that although from a logical analysis of the concept of momentum (momentum = mass x velocity) the most efficient learning sequence might well be conservation of matter ⟶ speed ⟶ proportional use of mass and speed with momentum held constant ⟶ momentum, it appeared from the study of young children that the psychological sequence of understanding was in fact momentum ⟶ conservation of matter ⟶ proportional use of mass and speed speed. Raven's findings supported our view that momentum was indeed a concept children already hold at quite a young age, (age 5^{+}).

The second reasons for placing emphasis of momentum relates to the teaching of physics at more senior levels. At senior secondary school and first year university levels, momentum is often introduced before force: Force is then defined as the rate of change of momentum with time, as suggested by Newton. More recently di Sessa (1980) has shown how many mechanics' problems can be solved using momentum ideas.

All the above therefore encouraged us to attempt to teach force through momentum ideas. An initial framework was developed and some of the teachers working in the group, as well as some of their school colleagues, adopted this framework and modified and expanded it into suitable teaching activities.

The resulting teaching sequence was a first draft of the activities provided in Working Paper No. 34. However some of the activities were modified substantially as a result of the trials (see later). Four teachers tried the material with a Form 1 class, two Form 3 classes and two Form 4 classes. Later the material was tried in a modified form with other Form 1-4 classes.

RESULTS OF THE TRIALS

The classes were surveyed prior to and after the teaching sequence using Survey A and then Survey B.[1] The reaction of the teachers to the teaching sequence was positive, they enjoyed teaching the sequence of lessons and pupils appeared to have no difficulty in appreciating the concept of momentum. As one teacher said;

> "I had no difficulty getting across the idea of momentum, it seemed that they already had the idea before I taught them."

This type of comment very much supported our ideas that it is so important to design teaching activities which build on, rather than ignore, children's views. However the results of the post-teaching survey were less encouraging. Typical results are given in columns I and II of Table I. It appeared that the teaching had reduced the number who considered energy to be a force but had increased the number who considered momentum to be a force. In other words we now had the label momentum attached to their concept of the physicists' momentum but children still had not distinguished clearly the differences between momentum and force nor clearly understood that momentum is not a force!

Of course some children had modified their views and their comments encouraged us to continue further with our approach. Joel was an 11 year old who changed his views from b-c-a to a-a-a (for questions 1-3 of Survey B) during the trial teaching sequence.

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[1] A copy of Survey B is provided in the Appendix. Survey A is a parallel form of this Survey (see Working Paper No. 34).

TABLE I: TYPICAL RESULTS OF THE TRIALS (References in Terms of Survey B - Appendix A)

Key: I - pre-teaching survey
II - post-teaching survey
III - post-post teaching survey
IV - post-teaching survey using a modified teaching schedule

		Form I (mixed ability)			Form III (average ability)			Form IV (upper ability)			Form IV (lower ability)		Form IV (top stream)
		I	II	III	I	II	III	I	II	III	I	IV	IV
Q.1,2,3	bca	11	19	5	16	18	1	15	20	1	24	12	3
	aaa	1	5	19	1	0	17	3	0	17	2	10	23
	aca	0	2	2	5	1	0	1	1	0	0	4	1
	baa	6	2	3	2	2	0	5	0	2	0	1	1
	acb	2	1	0	1	4	2	1	0	1	0	0	0
	aab	2	0	1	0	0	5	0	1	0	1	0	0
	other	12	4	4	4	2	0	1	0	0	1	1	3
Q.4	gravity + friction	1	9	18	1	8	19	3	3	18	1	6	14
	gravity + kick	9	4	3	11	8	4	9	3	0	11	8	7
	gravity	0	8	3	3	0	0	1	0	0	0	6	4
	friction + kick	7	4	0	1	5	0	0	0	1	4	0	3
	friction	0	3	3	1	0	0	0	0	0	0	2	0
	kick	11	2	3	11	2	0	3	6	0	9	3	1
	friction, gravity, kick	6	4	4	1	4	1	11	10	3	3	3	0
Q.5	zero total force	7	27	26	15	20	24	14	21	22	7	22	20
	downwards	16	4	6	9	6	1	13	1	0	11	3	6
	no force	11	3	2	5	1	1	0	0	0	10	3	3
Q.6	Yes, gravity	22	26	28	26	20	24	25	19	21	24	27	27
	no, not moving	12	8	6	3	7	2	2	3	1	4	1	2
Q.7	force	25	26	32	26	22	25	27	2	19	22	27	26
	no, force	9	6	2	3	5	1	0	20	3	6	1	3
Q.8	push	6	30	32	16	20	23	16	19	19	8	23	26
	pressure	17	8	6	16	11	0	12	1	1	23	11	0
	pull	8	28	31	11	19	23	15	19	19	6	24	27
	energy	14	0	0	8	7	0	9	2	2	12	3	0
	momentum	2	12	4	0	8	0	1	3	1	2	4	0
	motion	12	2	0	3	2	1	7	1	1	3	2	0
	push and pull (together)	1	4	16	1	8	23	10	14	17	0	16	26
Q.9	gravity	10	2	3	3	1	0	0	1	0	0	0	2
	friction	8	12	14	8	15	21	22	16	20	3	17	19
	stopped naturally	6	1	0	3	0	0	1	0	0	2	1	3
	ran out of force	7	17	4	15	11	4	4	3	2	23	10	5
Q.10	no total force	14	27	27	15	6	17	7	15	22	5	7	17
	total force	17	6	6	4	21	9	20	9	0	23	21	12

R. "What has Mr S. been talking about?"

J. "About force and momentum." ("Anything else?") "About how forces are related in different ways and how it is applied to objects."

R. "Pushes and pulls?" ("Yes.") "Okay, well here are three words ... FORCE - MOMENTUM - PUSH/PULL ... are we talking about different things or the same thing?"

J. "Well force, push and pull are pretty much exactly the same ... but momentum is not." ("How is it different?") "Well the momentum is how the object has speed but force is just what starts it off."

R. "Do you remember doing these questions for Mr S?" ("Yes.") "Can you remember what you put for the first three?"

J. "They are all (a) ... well because when the ball is on the way up ... the force on the ball is downward because of gravity, and once the ball has left the guys hand there is no more force on it except for gravity ... and when the ball if just at the top there is still gravity pulling it down ... which is why it has stopped ... and when it is on the way down there is of course, force pulling it downwards from gravity."

R. "Can you ... before he started teaching these things he had another set of questions similar to these ... I don't know if you can remember about that?"

J. "Yes ... I think I said that on the way up the force was upwards ... and then when it was at the top there was no force because it wasn't moving ... and when it was on the way down the force was pulling it downwards.

R. "So during the lessons you changed your mind about that?" ("Yes.") Can you really remember what it really was that Mr S. said that made you change your mind about that?"

J. "Well it was how he said that no matter what there is always gravity ... because gravity is always pulling down."

R. "And that is the thing that really sort of made you think about it?" ("Yes.") Right ... now we have got a real problem because what we are trying to do is to teach ideas about force and momentum and pushes and pulls and you seem to have got it pretty right in terms of what we were trying to teach ... but there is a lot of people in your class who even despite all that teaching by Mr S., chose (b)-(c)-(a) beforehand and still chose (b)-(c)-(a) afterwards ... in other words they didn't change their mind at all ... and that's a real problem ... we don't know how to get over that ... do you see how we might teach it to get other children to see it the same way that you see it?"

J. "Well we had limited teaching ... so if there was a longer period of time it might get through ... also I think if he demonstrated that there was always gravity pulling it down which is why it slowed and stopped on the way up ..."

R. "It is very important to you to have that idea?" ("Yes.") "When you say you had limited teaching ... what did you mean by that?"

T. "We only had four one-hour periods ... two were on momentum and two on pushes and pulls and force. He demonstrated on the last day about pushes and pulls and how there is gravity and if something is on the ground there is still gravity which holds it there ... if he took a little more time over it ... and really got it through ... and worked with each person individually ... and had a few more tests they would get it. I think."

R. "You don't think it is impossible to teach to 11 year olds?"

J. "No ... not at all.

Joel gave us the encouragement to continue our experiment!

FURTHER TRIALS

Faced with the disappointing post-survey results (columns II - Table I) a variety of approaches were adopted. With the Form 1 class an additional lesson was given. In this lesson a real effort was made to show the difference between momentum in a body and the force on a body. The results of this lesson appeared considerably significant as can be seen from the Form 1 results, column III - Table I. This post-post-survey was administered six weeks after the additional lesson.

With the Form 3 and Form 4 classes the results of the post-survey was discussed after the pupils had completed the survey and the correct scientific answer was discussed. With these classes the pupils were given an unannounced post-post-survey some four to five weeks later. The results of this final survey were quite dramatic (see Form 3 and 4, Column III results - Table I). A number of students were interviewed following this test. It certainly appeared that the pupils hadn't superficially learnt the right answer but now had a good understanding of momentum and force. The following is an extract from one interview where a pupil had explained that he had changed his ideas both during the teaching and during the discussion of the post-teaching survey.

I. "So some of the ideas you have always had, some of the ideas you changed during the teaching, and some of the ideas you changed when Mrs XXXXX went over the test?"

G. "Yes."

I. "And that was because Mrs XXXXX taught you when she went over the test or because you learnt some of the tricks in the questions?"

G. "Because I learnt some of the tricks in the questions."

I. "So you think if you did change your ideas it was during the teaching rather than just when she went over the test?"

G. "Well when she went over the test it meant that I had different ideas to the answers ... and that means that I knew that I had to change my ideas ... so I changed my ideas when I knew what was right ... when I was sure it was right."

I. "So the test made you aware of how your ideas were different to the right ideas ... but what ... you didn't know ... you weren't very clear ... exactly what the science idea was or exactly what your idea was?"

G. "I knew what she was talking about when she was teaching us ... but my ideas were slightly different.

This pupils final comment is a very profound statement. The advantage of feedback from well designed surveys and tests is obvious - such feedback leaves no room for ambiguity or misinterpretation.

Following the above work, a modified teaching strategy including a greater emphasis on the distinctions between momentum and force was developed. The results of the post-test following this teaching sequence (see column IV of Form 4 (low ability) results - Table I) gave some cause for optimism. Although these results are not dramatic, for example 57% choosing a-a-a after the teaching sequence, it must be noted that this was a lower band 4 form (top 40% of ability range absent). The results must also be compared favourably with the results given on p.5 of Working Paper No. 33, where only some 20% of sixth and seventh form physics chose a-a-a.

Further trials with some of the material, including classroom observations of children using the worksheets, led to the finalized Working Paper No. 34 - Teaching about Force. This document is not seen as an end point but, with the surveys included there, it is hoped that the activities provide a basis on which a worthwhile teaching sequence can be developed and subsequently improved further by individual teachers using their own post-survey results as a guide for further changes.

In addition to all this work one of the group (B.N.) tried an alternative approach with a top stream fourth form. This class used a ISCS individualised approach using the unit "Forces in Action". Many of the ideas on force and motion that we were interested in, were however not considered by this unit. The key ideas not included tended to be discussed formally with the whole class at appropriate stages during the series of lessons. From our visits to this classroom it appeared that the pupils had carried out many activities involving force in an informal self-paced environment which contrasted strongly with those few occasions when pupils were taught briefly in a formal situation about one or two key features of force and its relationship to motion. Unfortunately a pre-teaching survey was not given to the class, but the post-teaching survey showed promising results (final column of Table I). However it must be emphasized that this was a top stream class and that both the teacher and ourselves consider the approach used was only suitable for a class of such ability.

FURTHER COMMENT

The work carried out by the physics action group has a number of other interesting aspects associated with it.

As we were able to show from interviewing some of the Form 1 pupils a month after the sequence of work, some 11 year olds had dramatically changed their views about force and motion to ones which were scientifically sound. Undoubtedly many of these were the brighter pupils. However these are our future scientists and they are capable and ready to understand these ideas at that age.

One of us (B.S.) taught both the Form 1 mixed ability class and the Form 4 lower band ability class. In our view the Form 1 class were more eager to learn and to modify their views than the older students. One is left with the impression that children may ossify into their children's science view unless it is challenged when children are young. This is reinforced to some extent by the efforts of the other author (R.O.) to teach the ideas to first year University physics students. Despite considerable emphasis in lectures on this topic (naturally using a somewhat different approach to that proposed for Form I-IV) the post-survey results (see Appendix B for further details of the questions used) showed only a marginal change from a pre-test survey using Q.1-3 of Survey B (see Table II). Admittedly the post-post-survey (using question of Appendix B in the final examination) showed a much more substantive change. However this work suggests to us that it may not invariably be better to delay the teaching of an idea to a later age level just because it appears difficult.

Table II: Percentage Results of the First University Physics Students (N ≈ 140) on Q.1-3 of Survey B and Alternative Forms of this Question (See Appendix B)

	Pre-test	Post-test	Post-Post-test
a-a-a	45	49	87
b-c-a	42	25	5
a-c-a	10	9	4
a-c-b	-	9	1
b-a-a	1	8	3

If there is some substance in the above, then the problem is to find the age at which intellectual maturity is sufficient to appreciate the ideas but, on the other hand, the child has not become too fixed in his or her viewpoint. One is also of course left to ponder how appropriate it is for all children at any one particular age level to be exposed to the same learning experience.

It was also clear from some of our interview work that often children need time to think about an idea before they accept it as the way they will think about things. During two post-teaching interviews of 11 year olds, who still considered answers b-c-a were the best answers to questions 1-3 of Survey B (see Working Paper No. 34); the interviewer at the end of the interview (R.O.) put forward his view that because the pull of gravity was always acting, he preferred answer a-a-a. "Did they prefer a-a-a or b-c-a as the way they thought about it, now?" Both independently stated at that time that they preferred b-c-a. However in a class discussion some two weeks later both pupils were arguing vociferously for answers a-a-a, even though the interviewer was not present on that occasion.

Finally some will suggest that we shouldn't be trying to teach abstract concepts like force to 11 year olds. Perhaps so, yet Worksheet A (p.8 of Teaching about Force - Working Paper No. 34) can have a mixed ability class of 11 year olds <u>all</u> discussing in small groups whether forces are present or not in the particular situations shown. The abstractness of a particular concept is certainly of less importance if one has a definite concept attached to the label and it has applicability with respect to the instance being discussed. We believe intellectual discussion of this type is important so that children can challenge the views of others and have their own views challenged. Such is the best traditions of science and scientists.

We end with a quote from a fourth form teacher's comments about the trial unit.

R. "A lot of people would say that you know that girls are not as interested in, or as motivated in things like chemistry or physics as boys."

T. "Oh, I don't find that at all! Especially this last one we just did on force ... I couldn't get them off it ... I couldn't get them away from it ... we could have spent the rest of the year on it ... normally they are not too happy to sit and talk about things they like to do practical work and I like to encourage them to do practical work ... we didn't do very much practical work with that one ... yet they sort of sat and asked me questions day after day after day ... they had obviously done the thinking about it themselves and they would have gone on forever."

R. "So those activities ... did you do some of those pencil and paper kind of activities?" ("Yes.") "They in fact promoted the kind of discussion that ..."

T. "That was one case ... where ... I mean they had already done these things themselves like pushing people ... or on skateboards ... trying to pull someone along in a box and this sort of thing ... they know what would happen so that you didn't really have to demonstrate the thing over again ... oh, we did do some silly things like ... see if you could pull two of us together in a cardboard carton and this sort of thing but they had the ideas in their head and they were really keen to sort them out.

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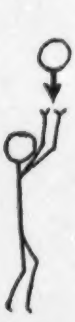
APPENDIX A

LEARNING IN SCIENCE PROJECT

Force - Survey B

1 - 3. A netball player sends a ball straight up into the air just a small way. The questions are about the total force on the ball.

1. If the ball is on the way up, then the force on the ball is shown by which arrow?


(a)

(b)

no force

(c)

2. If the ball is just at the top of its flight, then the force on the ball is shown by which arrow?

(a)

(b)

no force

(c)

3. If the ball is on the way down, then the force on the ball is shown by which arrow?

(a)

(b)

no force

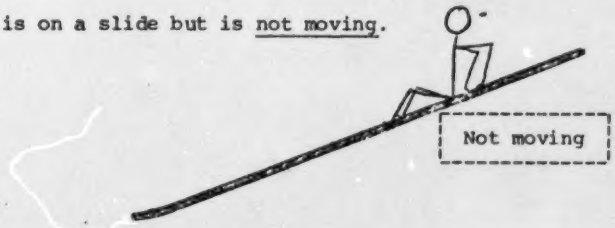
(c)

4. A soccer ball is kicked into the goal.

As it moves into the goal what are the forces on it?
(you can choose more than one)

(a) The force of the kick
(b) The force of gravity
(c) The force of friction

5. A person is on a slide but is <u>not moving</u>.



Which of the following is correct?

(a) There are many forces on the person but the total force is zero
(b) There are many forces on the person and the total force is downward
(c) There are no forces on the person at all

6. A diver steps off the end of a diving board very gently and slowly.

Just after she has stepped off, but <u>before she really started to drop down</u>, would there be a force on the diver?

(a) Yes, there is gravity
(b) No, she is not moving

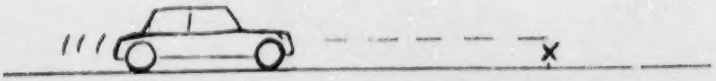
7. A person is leaning against a building. Is the person putting a force on the building?

(a) Yes
(b) No

8. Which of the following words give the best idea of force?
(you can choose more than one)

(a) motion (b) momentum (c) energy
(d) pull (e) pressure (f) push

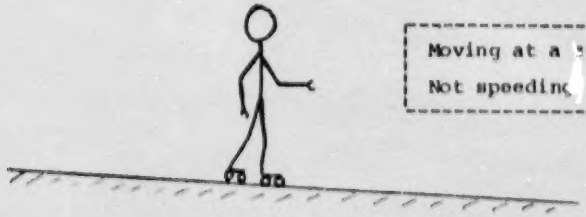
9. A car is travelling along a flat road when the engine stops going. The car slows down and stops at X.



Which of the following could explain this? (choose one)

(a) Gravity caused the car to stop
(b) Friction caused the car to stop
(c) The car just stopped naturally
(d) The car ran out of force

10. A person on roller skates moves along a gently sloping path. The person is going at the same speed all the time. She is not getting faster or slower.



Moving at a steady rate.
Not speeding up or slowing down.

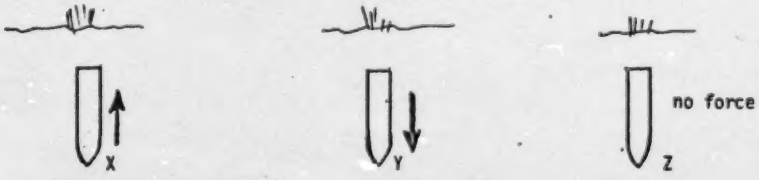
Which of these sentences about the total force on the skater is correct?

(a) There is no total force on the skater because her speed is steady
(b) There must be a total force on the skater because she is moving

APPENDIX B - THE ALTERNATIVE FORMS OF Q.1-3 SURVEY B USED WITH THE UNIVERSITY PHYSICS STUDENTS

(a) The term test question which acted as a post-test where compared to Q.1-3 of Survey B. X is equivalent to a, Y to b, and 2 to c. Hence answer (c) (X-X-X) is the correct scientific response.

A used fuel tank from the SPACE SHUTTLE falls vertically into the sea. It travels vertically a small distance below the surface before re-emerging on the surface.
The following three diagrams represent possible directions of the total force on the tank.



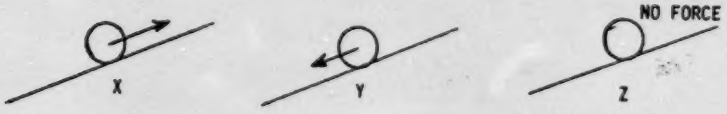
The total force on the tank i) just before it reaches maximum depth,
then ii) when it is at greatest depth,
then iii) when it is on the way up,

is best represented by the sequence;

(a) Y - Z - X
(b) X - Z - X
(c) X - X - X
(d) X - Z - Y
(e) Y - X - X

(b) A final examination question which acted as a post-post-test were compared to Q.1-3 of Survey B. X is equivalent to b, Y to a, and Z to c. Hence answer c (Y-Y-Y) is the correct scientific response.

A tennis ball rolls up a small incline, comes to rest, and then rolls down again. The following three diagrams represent possible directions of the total force on the ball.



The total force on the ball i) just before it reaches maximum height
then ii) when at the greatest height
then iii) when it is on the way down

is best represented by the sequence;

(a) X - Z - Y
(b) Y - Z - Y
(c) Y - Y - Y
(d) Y - Z - X
(e) X - Y - Y